NBSIR 75-971

A Fire Hazard Evaluation of the Interior of WMATA Metrorail Cars

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Center for Fire Research
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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, *Secretary*
James A. Baker, III, *Under Secretary*
Dr. Betsy Ancker-Johnson, *Assistant Secretary for Science and Technology*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

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A FIRE HAZARD EVALUATION OF THE INTERIOR OF WMATA METRORAIL CARS

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Abstract

A series of fire tests was conducted for the Washington Metropolitan Area Transit Authority to assist them in assessing the potential for fire hazard in the new Metrorail subway cars. Results of small-scale laboratory tests were found inadequate for this assessment. Results of full-scale tests on mock-ups of the interior (and on a real car for a smoke penetration test) show that the potential for hazard arises primarily from the seat padding and covering and from the plastic wall lining. The hazard arises both from smoke development and from spread of flame and heat. The times to reach unacceptable conditions has been determined for several test conditions. It is recommended that the authorities review these times in the context of what they consider to be appropriate times for safe escape. Recommendations are made for increasing the amount of time available for escape. These would require changes in the seating and wall lining materials.

Key words: Flame spread; flammability; full-scale fire tests; laboratory fire tests; Metrorail cars; neoprene; smoke; transportation; urethane.

1. INTRODUCTION

Experience has taught that fires can occur in and around a subway car. A fire originating in a subway car may represent a serious hazard to the car occupants if there is a possibility of the rapid development of heat, smoke, and toxic products, and difficulties involved in rapid evacuation [1,2][1].

In the past, most subway fires have been attributed to the high voltage (600-700 volt) feeder system. This can be caused by third rail arcing or shorting, by breakdown of the insulation in the motor control boxes or other parts of the electrical system, or by leakage of current due to dirt and grease collecting on the underside of the carriage.

In general, a small percentage of fires appear to have originated in the interior of the subway car. However, most subway cars in the past have been furnished with materials which were noncombustible or difficult to ignite. Current design concepts incorporate an increased

[1] Numbers in brackets refer to the literature references listed at the end of this paper.

emphasis on the aesthetic impact of a car's interior with an attendant growth in the quantity of combustible materials. The relative increase in the ease of ignition of these materials as compared to earlier models increases the likelihood of major fires in the interior of the car [2].

Under a contract with the Washington Metropolitan Area Transit Authority (WMATA), a program was conducted at the Center for Fire Research (CFR) of the National Bureau of Standards (NBS) to assess potential fire and smoke hazards represented by various materials that are being incorporated into a rapid rail system currently under construction in the Washington, D.C. Metropolitan Area. This program primarily addressed the question of the relative fire safety of the interior funishing of the subway car. It was not a complete fire safety analysis of the subway system, which would include consideration of evacuation, tunnel and station design, communications, firefighting, etc. The program was conducted in three parts:

1. Small-scale laboratory tests were performed on materials from the various components used on the interior of the Metrorail car.

2. A separate test was also conducted to ascertain the likelihood of fire or smoke from an ignition below the floor system penetrating to the car through the floor.

3. Seven fire tests were conducted on a mock-up car interior in order to determine the overall effects of an assembled system as compared to the fire performance characteristics of the individual components.

2. TEST RESULTS

2.1. Small-Scale Laboratory Tests

Interior finish materials proposed for use in Washington Metropolitan Area Transit Authority (WMATA) Metrorail cars were subjected to appropriate small-scale tests. The subassemblies that were tested included: 1) interior walls, 2) carpet with integral pad, and 3) seat cushions. The subassemblies were evaluated using NFPA 258T smoke density chamber [3], the FAR-25.853, vertical test [4], and the ASTM E-162 radiant panel test method [5]. (The seat cushions were not tested by ASTM E-162.) In addition, two special tests recently developed at NBS to evaluate fire performance for specific product end-uses were performed. These were the Flooring Radiant Panel Test (FRPT) [6] for the carpet; and the upholstery test [7] for the seat cushion. Results of the laboratory tests are listed in table 1.

In addition, all synthetic materials were chemically characterized by infrared indentification of the base polymer and the use of X-ray fluorescence for the qualitative determination of the presence of flame retardant additives. These data are presented in table 2.

2.1.1. NFPA - Smoke Density Chamber

This test method measures the smoke generation of solid specimens exposed to a radiant flux level of 2.5 W/cm^2. The smoke produced by the burning specimen is measured by the attenuation of a vertical beam of light passing through the chamber. The maximum attenuation of the light beam by the smoke is a measure of the optical density or "quantity of smoke" that a material will generate under the given conditions of the test. The smoke data presented in table 1 were taken under flaming ignition conditions, with the specimen in the vertical position, and represent the maximum optical density, D_m, for the various materials. In order to place these results into proper context, comparable results for other materials such as plywood and red oak are 45 and 30, respectively [8].

The measured D_m values were found to be relatively high for all of the materials tested. (The integral skin urethane foam seat cushions had a D_m value that was 6 times that found for the seating in the Metrobus [9].) This large increase may be the result of the high density of the integral skin urethane foam cushions. The wall material also had a relatively high D_m value compared with comparable-use materials tested in other programs.

The D_m values represent a measure by which materials can be placed in a relative ranking. To use the test results in predicting smoke level in a given space, one must know precisely quantity, amount burned, and ventilation. They are not known well enough in the present case, principally because of uncertainties regarding ventilation.

2.1.2. FAR-25.853

This standard, used by the Federal Aviation Administration, defines both a test procedure and test criteria that determine acceptable small-scale fire performance for compartment interior materials on transport category airplanes. The test procedure outlined in this standard is a vertical test with a 3.9-cm (1.5-in) flame applied for either 12 seconds or 60 seconds (determined by the end-use of the material) to the lower edge of a 5-cm (2-in) wide by 30.5-cm (12-in) long specimen. The test records the flame time, burn length, and flaming time of dripping material. The test criteria require that specimens self-extinguish, with a burn length not exceeding 15 to 20 cm (6 to 8 in) (depending on the end-use), a flame time not exceeding 15 seconds after removal of the burner, and flaming on the floor of the cabinet not to exceed 3 to 5 seconds (end-use dependent).

This test procedure was applied to the interior finish materials (walls, carpet, and seat cushions) proposed for use in the Metrorail car. All of the proposed materials passed the test criteria (see table 1).

2.1.3. Radiant Panel Test (ASTM E-162)

This method measures flame spread and heat release under a varying radiant flux range from 4 to 0.3 W/cm^2. A flammability index, I_s, is defined as the produce of the flame spread factor and the heat release of a burning sample. The higher the index, the greater is the flammability. The values tabulated in table 1 represent the flammability indexes found for the carpet and wall lining. An I_s value of less than 75 is considered acceptable for the walls and ceilings of corridors in commercial buildings, but a value of less than 25 is commonly required for corridor linings in institutional buildings.

2.1.4. NBS Flooring Radiant Panel Test

This test method exposes a specimen placed horizontally to a radiant energy gradient that varies along a 1-meter length from 1.1 W/cm^2 to 0.1 W/cm^2. The specimen is ignited by a small flame at the high energy end. The distance burned to the point at which the flooring material extinguishes itself determines the critical radiant flux (CRF) necessary to support continued flame propagation. The higher the CRF, the better is the fire safety of the carpet.

The carpet specimen did not ignite in this test. That means that the critical radiant flux necessary to support combustion on the carpet surface is greater than 1.1 W/cm^2. A fire initiated on the carpet, e.g., from a newspaper would not propagate; nor would a fire on a seat assembly cause propagation on the carpet more than a few inches from the exposure area.

2.1.5. Upholstery Tests on Urethane Seat Assemblies

A test method has recently been developed at NBS to determine the ignitability of upholstered furniture when exposed to a lighted cigarette. The test, to determine if an assembly does or does not ignite, is performed on flat surfaces (i.e., seat cushions) and in the crevices on the entire assembly (i.e., junction of the back and seat cushions). Only the original integral skin urethane seats were tested according to this test method. The seat assembly did not ignite when in contact with a lighted cigarette.

Another series of tests were conducted, using a methenamine pill ignition source in place of the cigarette. The pill, placed in various areas of the seat assembly did not produce an ignition. As many as 11 pills were placed on the seat cushion without producing a sustained ignition.

Various other low-level ignition tests were used to determine the ignitability level of the integral skin urethane seat cushion. The addition of two pills to an already burning pill in a crevice caused

ignition and self-sustained burning of the seat assembly. The same was found to be true if a book of matches replaced the pills. In a subsequent test, lighter fluid was poured onto the seat assembly and ignited with a match. The lighter fluid burned without igniting the seat assembly. A follow-up test was conducted by pouring lighter fluid in a 0.64-cm (1/4-in) deep slit cut into the seat cushion. This resulted in ignition of the seat cushion.

These results indicate that the car interior may not readily be ignited by very small ignition sources.

2.2. Metrorail Car Test - Smoke Penetration

Non-destructive testing on a completed Metrorail car was performed to evaluate the integrity of the floor assembly against the passage of smoke into the interior compartment from an exterior fire. Since the car's floor assembly could not, for economic reason, be exposed to an actual fire condition, these tests were designed to be non-destructive and to reveal the existence of any "holes" in the floor assembly as a result of construction procedures.

A plastic skirt was built around the perimeter of the car. Three ionization-type smoke detectors were located along the center aisle of the car approximately 0.91 m (3 ft) from the floor opposite each side exit door. A combination of one- and three-minute smoke bombs were placed in four different locations below the subway car and ignited.

In addition to the ionization detector, visual observation within the car with a high intensity lamp was conducted. This test was repeated with negative results each time. As long as 10 minutes after ignition of the smoke bombs, no detectable leakage into the car interior was observed.

2.3. Full-Scale Car Mock-Up Tests

Seven fire tests were conducted on a mock-up Metrorail car interior. The mock-up contained floor, wall, and ceiling sections plus three seat frames - two transverse double seats and one lateral single seat (fig. 1). All full-scale tests were done on or under the center assembly shown in figure 1. The floor was carpeted. The seat cushions varied from test to test (see table 3).

No fire endurance tests were run on the floor assembly. The construction of the floor is, in our judgment, such as to provide about 10 minutes resistance to the fire penetration in the standard ASTM E-119 [1].

While the small-scale tests on subassemblies have a well defined rating scale, full-scale tests require a subjective evaluation. This evaluation was made in terms of vertical and horizontal flame spread,

temperature rise, and smoke density. Two general criteria were used to evaluate the full-scale tests: 1) that there shall be no significant spread of fire from the seat of ignition; and 2) the smoke level shall be such as to allow egress in a reasonable time from a burning car. The test was conducted using one of three levels of energy to start the fire.

1. The least intense ignition level used was a paper trash bag containing one full sheet of newspaper - 30 g (1 oz).

2. A second and higher level of ignition source was .45 kg (1 lb) of loosely stacked newspaper.

3. The highest intensity ignition source was the equivalent of a Sunday newspaper - .91 kg (2 lbs) of loosely stacked newspaper.

These were used at three different locations as outlined in table 3.

2.3.1. Integral Skin Urethane Foam Seat

There were three full-scale tests (Nos. 1, 4, and 6) with an integral skin urethane foam seat cushion. These tests involved the same foam formulation, but differed in the amount of flame retardant additive. Tests 1 and 4 were on the outboard seat with a trash bag and .91 kg (2 lb) newspaper, respectively, as the ignition sources. Test 6, series 20 foam, involved a trash bag placed on an aisle seat.

In all three cases, ignition of the foam occurred approximately two minutes after ignition of the trash bag or newspaper. At this time, the apparent rate of smoke evoluation increased. In Test 1, the rate of fire growth was very slow. It took 16.5 minutes for the fire to grow to a sufficient size to ignite the adjacent wall panel. After the ignition of the armrest on the wall panel, flame progressed rapidly up the wall and the fire was extinguished 18.5 minutes after ignition of the trash bag.

Initally, Test 4 was similar to the previous test. The seat back became involved two minutes after the newspaper was ignited. However, due to the large ignition sources, the armrest began to char 6 minutes into the test and finally ignited one minute later. Flame spread was very rapid and, at approximately 9 minutes after ignition of the newspaper, the window fell out of its frame followed immediately by the complete involvement of the side wall panel. The test was terminated 9.8 minutes after ignition.

Test 6 was an aisle seat ignition using a trash bag as the ignition source. Ignition of the foam occurred in approximately 2 minutes. The seat back became completely engulfed in flames 8.3 minutes into the test. Flames on the seat cushion were confined to the back half of the cushion.

The second seat back, the outboard seat of the same seat assembly, ignited 2.2 minutes later, 10.5 minutes after ignition. The fire was extinguished 11 minutes after ignition, before it had spread completely across the second seat involving the wall panel. After the test, inspection of the wall panel revealed areas of softening but not charring. During this entire test, three animals housed in a specially designed cage, were exposed to a fraction of the total combustion gases produced. Their response characteristics during the test and their biochemical characteristics after the test were recorded (see section 3.4.).

2.3.2. Vinyl-Covered Neoprene Foam Seat Cushions

Three tests (Nos. 2, 3 and 5), using vinyl-covered neoprene foam seat cushions, were performed in the full-scale mock-up of the subway car. Each test was conducted with the ignition source in a different location (see table 3).

In Test 2, .91 kg (2 lbs) of newspaper were loosely stacked on the outboard seat. Approximately 2.5 minutes after ignition of the paper, the seat back ignited. This caused an increase in the rate of smoke evolution followed by a softening of the wall panel, 4.5 minutes into the test. The wall panel separated at the seam line exposing the insulation behind it, 8.3 minutes after ignition, and finally ignited at 11.5 minutes. The ensuing flame spread was vigorous and the fire was extinguished approximately 12 minutes after it began.

In Test 3, .91 kg (2 lbs) of newspaper were loosely placed below the center seat assembly on the outboard side. Approximately 2.5 minutes after the test began, the vinyl upholstery on the seat cushion directly above the ignition source had begun to char. Thirty seconds later it was noted that large amounts of gray smoke were being produced by the seat cushions. For the next 17 minutes, the ignition source burned at a steady rate and smoke was evolving at a reasonably constant rate from the seat cushion. Test 3 was terminated after 20 minutes with minimal damage to the subway car assembly. Throughout this test there was no visible indication of flame spread across the upper surface of the seat cushion. After the test, an inspection of the mock-up assembly revealed several areas of charring along the lower wall panel. The carpet was damaged in the area covered by the ignition source; however, there was no indication of flame spread along the carpet surface. Smoldering of the adjacent seat cushion had been initiated by the newspaper fire, but there was no accompanying flame spread.

Test 5 was carried out on the aisle seat with .45 kg (one pound) of newspaper loosely scattered on the seat cushion. The seat back ignited 4.5 minutes after ignition of the paper. The seat back aisle cushion continued to burn for the next 16 minutes when approximately 80 percent of the upholstery had been consumed. Throughout this time period, a dark gray stream of smoke was being produced. A fraction of the smoke was introduced into a suitably designed chamber containing three animals

as in Test 6. The test was completed in 20.3 minutes. In this test, the vinyl-covered neoprene seat cushions did not propagate a flame beyond the seat of origin.

2.3.3. Blank Test

It was noted in earlier tests performed on outboard seat cushions, both urethane and vinyl/neoprene, that the ignition of the wall panels represented a critical end point in determining the future course of the fire. Therefore, a test was conducted whose purpose it was to determine the role of the wall panels in passing or failing the criteria previously outlined for the entire subway assembly.

In this experiment, the seat cushions were replaced by an asbestos-cement board. .91 kg (2 lbs) of newspaper were placed on the outboard side of the seat frame. Ignition of the armrest occurred 2.3 minutes after the start of the test. It took an additional 30 seconds before stable burning developed on the armrest and, for approximately the next 4 minutes, flaming combustion was confined to the lower half of the wall assembly. From 7.3 to 8.0 minutes after the ignition of the newspaper, flaming was evident on the upper wall panel at which time the access door in the upper portion of wall panel swung out of the path of the fire. With the removal of combustible material above the flame front, burning progressed very slowly in the horizontal direction towards the forward seat assembly. Thirteen minutes after initial ignition of the newspaper the test was terminated.

3. ANALYSIS OF FULL-SCALE TEST RESULTS

3.1. Temperature and Heat Flux Data

Temperatures in various areas of the mock-up structure were monitored throughout each test. The upper compartment gas temperature relates to the possibility of full involvement of the combustible contents of the car interior [10]. The temperature of these gases was calculated by averaging the compartment gas temperatures at 7 locations, 25 to 50 mm (1 to 2 inches) below the interior ceiling. Figures 2 and 3 are the plots of these data for all 7 tests. The maximum average temperatures ranged from 55 °C to 288 °C. The blank test reached a maximum of 76 °C. This occurred shortly after the access door popped open and the flames began to spread horizontally.

The tests involving urethane cushions produced average ceiling temperatures ranging from 138 °C to 288 °C. The lower reading occurred during an aisle test where the test was terminated prior to the involvement of the wall. The highest temperature increase coincides with the ignition of the side wall panel.

The neoprene seat assemblies had lower average gas temperatures, even in the test that resulted in the ignition of the wall panel. This test reached an average gas temperature of 92 °C.

Figures 4 and 5 are floor to ceiling temperature profiles 1.4 m (4.5 ft) down the aisle from the ignition point. They represent the temperatures that existed at this location when the average upper compartment gas temperatures reached a maximum. In figure 4, only 2 neoprene tests are compared because the data for the vinyl/neoprene floor ignition test, Test 3, and aisle seat ignition test, Test 5, produced virtually identical temperature profiles. A comparison of Test 2 and Test 3 indicates the effect of the burning wall material in determining the temperature profile of the compartment.

A comparable comparison (fig. 5) of the urethane cushions shows higher overall temperatures and demonstrates again the effect of the burning wall lining.

The rate of heat transfer was recorded at three different locations in the mock-up assembly (see fig. 6). A total heat fluxmeter was placed in the floor of the mock-up, flush with the carpet surface, 1.2 m (4 ft) up the aisle from the ignition point. A second meter was placed in the forward wall, one meter (40 in) from the floor. The third was positioned perpendicular to the second, recording the heat flux seen by a seat assembly across the aisle from the ignition point.

The maximum heat flux readings and the time at which they occurred are summarized in table 4. The maximum readings were obtained in Test 4. Heat flux readings to the carpet reached a peak of .51 W/cm^2. This test was terminated at about this time because of the complete collapse of the mock-up interior. The time of maximum heat flux closely corresponded to peak temperatures in the upper gas layer of the compartment. Tests 2, 3 and 5, with the vinyl-covered neoprene seats show lower energy release than the integral skin urethane foam seats.

3.2. Smoke Data

To measure the optical density of the combustion products produced during the duration of the test, a smoke meter was installed in the mock-up subway car (see fig. 6). The light beam traversed the 2.5 m (8.5 ft) length of the compartment 1.5 m (5 ft) up from the floor. The attenuation of the light beam (measured by the optical density per meter) yields a measure of the smoke intensity in the compartment.

A summary of these data is presented in table 5. The times to reach an optical density per meter (OD/m) of .10 and .33 are listed, respectively. These values were picked as representing moderate and very dense smoke levels. Except for the first test, the data indicate that the time to .10 OD/m smoke density level was not a function of the seat cushion

material. The first test involved a trash bag ignition, that developed very slowly into a well defined fire. The test was terminated before the smoke level reached .33 OD/m.

For the remaining six tests, the time between a .10 OD/m and a .33 OD/m varied with the type of seat cushions used. A comparison of Tests 2 and 4 (fig. 7), shows that after the initial 4 minutes the change in OD/m was more rapid for the urethane seat assembly than for the vinyl-covered neoprene seat cushions. Even in those tests where the wall did not become involved, the difference in the OD/m was significant, the difference between Tests 5 and 6 is an example (see fig. 8).

3.3. Gas Data

The combustible gases were analyzed for CO, CO_2, and O_2 concentration in two locations within the test compartment at the ceiling and at 1.5 m (5 ft) from the floor (fig. 6). Two additional sampling lines were located near the ceiling in order to monitor the production of hydrogen chloride and hydrogen cyanide. In Test 5 and Test 6, an additional set of sampling probes was installed on the intake of the animal cage.

Previous studies have been conducted in order to determine human tolerance levels (i.e., incapacitation) for various time exposures of temperature, CO, CO_2, and O_2 concentration [11]. These are summarized in table 6. It should be recognized that these data represent approximate tolerance limits for individual gases and, therefore, ignore the effects of these gases in combination with each other and the possible presence of other gases in the combustion gas stream.

The peak gas concentrations and the time at which they occurred are summarized for all 7 tests in table 7. Except for the first test, peak gas concentrations of carbon monoxide and carbon dioxide occurred between 8.5 minutes and 9.3 minutes after ignition of the initial fuel source (i.e., newspaper or trash bag). Available oxygen was minimum at this time period. Comparing table 6 with these data, for the 5 second exposure level, shows that only Test 1 and Test 4 exceeded the 1.5 percent carbon monoxide limit. At the 1.5-m (5-ft) level carbon monoxide concentration never approached the limits listed in table 6. The carbon dioxide concentrations at both the ceiling and 1.5-m (5-ft) levels never exceeded the 5-second tolerance limit. In addition, the oxygen concentration never dropped below the hazard limit.

The small drop in oxygen concentration for all 7 tests indicates that the entire compartment was well ventilated. This mock-up was approximately 10% of the actual volume of the Metrorail car. However, the gas concentrations represent the conditions in the immediate vicinity of the fire and, without a known dilution factor, extrapolation to the full size car cannot be made. Since the actual subway car does not have a closed loop air supply system any fire occurring within a car would, initially, develop in the same manner as observed in these tests. This would continue until a ventilation restricted regime occurred.

Tolerance levels for rats when exposed to hydrogen cyanide, HCN, has been found to be 50 ppm. At this concentration level, incapacitation occurs in 3 minutes and death in 8 minutes [12]. In Test 1 and Test 4, the concentration of hydrogen cyanide was determined in the center of the ceiling of the mock-up subway car. Table 8 summarizes the HCN concentration levels within the subway car. These levels are below the exposure limits necessary to induce incapacitation in rats, ignoring any effects from other gases and not taking into account the dilution due to the scaling factor.

Hydrogen chloride was not detected in the combustion products of any of the 7 tests at the sensitivity of the instrumentation, which was about 50 ppm.

3.4. Animal Response Data[2]

In Tests 5 and 6, a specially designed animal cage was attached to an exhaust line so that a fraction of the combustion gases leaving the compartment were introduced to 2 rats trained to walk in a motorized rotating wheel. A third rat, untrained and cannulated in order to facilate the rapid removal of blood samples, was also placed in the cage. The animals' performances were observed throughout the duration of the test.

In neither of these tests did death occur. However, in Test 6, it was noted that one of the trained rats had difficulty in performing the required task (i.e., walking) 6.5 minutes into the test. At the completion of the test the second trained rat exhibited inconsistent behavior. Table 9 is a summary of the blood chemistry for the animals used in Tests 5 and 6.

4. DISCUSSION

While the results of the laboratory tests such as FAR 25.853 indicate that satisfactory fire performance was achieved for all the materials used in the interior of the subway car, the full-scale experiments show that these materials fail to perform in their end-use configuration as predicted by these small-scale tests. Also, the smoke generating properties of these materials, as measured by NFPA 258T, were found to be high. This finding was supported by the full-scale experiments.

The smoke penetration test demonstrated the effectiveness of the floor assembly in preventing the passage of smoke into the passenger compartment. This test, however, presumes that the floor assembly has the ability to resist a maximum 10 minute fire severity from an undercarriage fire.

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[2] For a detailed description of techniques used in the toxicological evaluation, see reference [12].

The full-scale tests, that were conducted to determine the interaction of the various interior components under fire conditions, indicated that the contribution of the carpeting and ceiling to initial flame spread and smoke generation was nil.

The integral skin urethane foam seat assembly (Test 6) spread fire to an adjacent seat from the seat of origin in 8 minutes, when using the smallest ignition source. In addition, in Tests 1 and 4, the fire spread to the adjacent wall panel.

The vinyl-covered neoprene seat (Tests 3 and 5) did not spread fire to an adjacent seat.

In Tests 1, 2 and 4, with a newspaper on the outboard seat, the fire spread from the seat of origin via the wall lining. In a subsequent test, it was demonstrated that the wall lining will ignite from a newspaper alone. If the urethane seats are replaced by the vinyl-covered neoprene seats, the major contribution to flame spread would come from the wall assembly.

While three levels of flame retardant urethane foam were tested, even the series 30, designated as the material with the highest level of fire retardant additive, ignited with a newspaper ignition source.

All full-scale tests show that smoke levels of .10 OD/m are produced in the vicinity of the fire in approximately 4 minutes or less after the start of the test. While the initial smoke level of vinyl-neoprene seat cushions are comparable to the urethane seat cushions, the further development of smoke is much slower for the vinyl/neoprene seats. Furthermore, since flames do not spread beyond the seat of origin, the total amount of smoke produced by the vinyl/neoprene is much less and will have a smaller affect on the rest of the subway car. These levels are not produced by the vinyl/neoprene assembly until 7-9 minutes (table 5). The urethane seat cushions could pose a serious smoke problem (.33 OD/m) throughout the car in approximately 5 minutes. Carbon monoxide buildup lagged behind smoke buildup by approximately 4-5 minutes.

The biological data and the gas analysis data suggest that the vinyl/neoprene seat assembly in the mock-up is less hazardous than the integral skin urethane foam assembly. This conclusion is supported by both the blood chemistry, behavioral observations of the animals and the chemical analysis of the combustion products.

5. CONCLUSIONS

1. The floor is unlikely to allow rapid penetration of fire and smoke from a fire beneath the car.

2. Results from small-scale tests, even when taken together, do not predict adequately the fire performance of the complete assembly.

3. The carpet and the ceiling do not contribute significantly to the initial fire hazard.

4. The seat padding and covering and the plastic wall lining are potential sources of fire hazard.

5. A criterion set forth in the Metro-NBS contract is that a test fire shall not spread from the area of origin. The urethane seating does not pass this criterion.

6. Vinyl-covered neoprene foam does pass this criterion when the test fire is on the aisle seat, namely, the fire does not involve the adjacent seat.

7. Test fires in seats next to the wall spread from the seat up the wall regardless of seat material.

8. Hazardous levels of smoke develop principally from the seating materials. About five minutes are required for such levels to develop from the urethane; about nine minutes for the neoprene system. The contribution from the wall lining generally comes later.

9. Hazards at these times appear to be due to the effects of smoke on reduced vision, rather than to the toxic effects of combustion products.

10. The time elapsed between ignition and development of hazardous levels of smoke from the fires in the seats is about 80% longer for neoprene seating than for urethane (nine minutes vs five minutes).

6. RECOMMENDATIONS

1. Metro should compare the time to develop dangerous levels of smoke or for the fire to spread from the area of origin with the time required to stop and evacuate a car.

2. If the urethane seating is judged by Metro not to provide sufficient time for safe escape, substitution of the neoprene foam system should be considered.

3. If Metro wishes to design in accord with the criterion that fire shall not spread beyond the area of origin, then both the urethane seating and the plastic wall lining must be replaced or upgraded.

4. Improved fire performance of the wall lining might be accomplished either by replacing it with a less combustible material (e.g. metal) or by improving performance through the use of more and better fire retardants, changed plastic ingredients, or some combination of these factors.[3]

7. ACKNOWLEDGEMENTS

Full-scale fire testing is a team effort. Therefore, the author wishes to express his appreciation for the effort put forth by the staffs of the Program for Fire Control-Construction and the Program for Toxicology of Combustion Products, Center for Fire Research.

8. REFERENCES

[1] National Bureau of Standards, Preliminary Report to Metro, Nov. 1974.

[2] National Academy of Sciences, Fire Safety and Fire Hazards Related to Polymeric Materials in Cars of Washington Metropolitan Area Transit Authority, 1975.

[3] Test Method for Measuring Smoke Generated by Solid Materials - 258T, National Fire Protection Association, 1974 NFPA Technical Committee Reports, Vol. IB, 1377-1424 (May 20, 1974).

[4] Federal Aviation Regulation - FAA Crash Worthiness Standard, Part 25, Section 25.853, Federal Register, Vol. 34, p. 13036 (Aug. 12, 1969).

[5] Surface Flammability of Materials Using a Radiant Heat Energy Source, E-162, American Society for Testing and Materials, Philadelphia, Pa. (1967).

[6] Benjamin, I. A. and Adams, C. H., Proposed Criteria for the Use of the Critical Radiant Flux Test Method, National Bureau of Standards (U.S.), NBSIR 75-950 (Dec. 1975).

[7] Proposed Standard for the Flammability (Smolder Resistance of Upholstered Furniture), Consumer Product Safety Commission, Unpublished.

[8] Lee, T. G., The Smoke Density Chamber Method for Evaluating the Potential Smoke Generation of Building Materials, National Bureau of Standards (U.S.), Technical Note 757 (Jan. 1973).

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[3] It is difficult to establish a performance criterion for this lining other than full-scale fire tests in a mock-up. However, a first step could be to obtain a flame spread in E-162 of about 25-30 and then proof test the product at full-scale.

[9] Braun, E., Report of Fire Test on an AM General Metro Bus, National Bureau of Standards (U.S.), NBSIR 75-718 (June 1975).

[10] Fang, J. B., Measurements of the Behavior of Incidental Fires in a Compartment, National Bureau of Standards (U.S.), NBSIR 75-679 (March 1975).

[11] Hafer, C. A. and Yuill, C. H., Characterization of Bedding and Upholstery Fires, Southwest Research Institute, Project No. 3-2610 (March 31, 1970).

[12] Birky, M. M., Coats, A. W., Alderson, S. E., Brown, J. E., Paabo, M., and Pitt, B., A Toxicological Hazard Assessment of Fire In A Metro-Rail Mock-Up, National Bureau of Standards (U.S.) NBSIR 75-966 (to be published).

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Table 1. Small-Scale Test Results on Metro Subway Car Components

Material	Test					
	Smoke Density Chamber	FAR-25.853		ASTM E-162 I_s (b)	Flooring Radiant Panel Test	Upholstery Test
	NFPA-258T D_m (a)	Burn Length (inches)	Flame Time (seconds)			
Carpet	694	2.5	3.5	8.1	DNI (c)	
Interior Wall	710	2.5	0	51.5		
Seat Cushion:						
Urethane (Original	632	1.3	9			DNI
Vinyl/Neoprene	678	3.0	0			

(a) D_m = Maximum Optical Density

(b) I_s = Flame Spread Index

(c) DNI = Did Not Ignite

Table 2. Chemical Analysis of Metro Subway Car Materials

Material	Base Polymer Identification
Wall Panel	Polyvinyl Chloride - Acrylic
Seat Shroud*	Acrylonitrile Butadiene Styrene - Polyvinyl Chloride
Carpet:	
Pile Fibers	Wool
Pad*	Polyurethane
Integral Skin Seat Cushions:	
Original	Polyurethane
Series 20*	Polyurethane
Series 30*	Polyurethane
Upholstered Seat Cushions:	
Seat Cover*	Polyvinyl Chloride (Plasticized)
Foam Cushion (Neoprene™)	Chlorinated Rubber

*May be flame retardant based on elemental analysis - X-ray fluorescence.

Table 3. Full-Scale Mock-Up Tests --
Seat Materials, Ignition Point, Ignition Source

Test	Seat Material	Ignition Source	Location
1	Integral Skin Urethane Foam*	Trash Bag - 1 oz (28.3 g)	On Outboard Seat
2	Vinyl-Covered Neoprene Foam	Newspaper - 2 lbs (0.91 kg)	On Outboard Seat
3	Vinyl-Covered Neoprene Foam	Newspaper - 2 lbs (0.91 kg)	Below Outboard Seat
4	Integral Skin Urethane Foam Series 30	Newspaper - 2 lbs (0.91 kg)	On Outboard Seat
5	Vinyl-Covered Neoprene Foam	Newspaper - 1 lb (0.45 kg)	On Aisle Seat
6	Integral Skin Urethane Foam† Series 20	Trash Bag - 1.5 oz (42.5 g)	On Aisle Seat
7	Blank†	Newspaper - 2 lbs (0.91 Kg)	On Outboard Seat

*Seat cushions originally supplied with cars

†Seat cushions replaced by sheets of canada board

Table 4. Maximum Rate of Heat Transfer for Three Locations In the Metro Subway Car Mock-Up

Test	Time (min)	Maximum Heat Flux (W/cm^2)		
		Floor	Side Wall	Forward Wall
1	18.33	.28	.28	.25
2	12.00	.07	.11	.12
3	9.00	.03	.02	.03
4	9.67	.51	.50	.42
5	9.17	.03	.05	.03
6	9.00	.15	.20	.17
7	8.50	.05	.10	.09

Table 5. Summary of the Smoke Obscuration Data for the Smoke Meter Traversing the Length of the Metro Subway Car Mock-Up (Optical Density per Meter)

Test	Time to .10 OD/m (min)	Time to .33 OD/m (min)	Extinguishment Time (min)
1	17.0		18.5
2	2.8	9.0	12.1
3	3.3	9.3	20.0
4	3.1	5.1	9.8
5	4.2	7.0	20.2
6	3.7	5.0	11.0
7	4.2	13.0	13.0

Table 6. Tolerance Levels for Various Time Exposures of Temperature, Carbon Monoxide, Carbon Dioxide, and Oxygen*

	Time: 5 Seconds	5 Minutes	30 Minutes
Temp. (°C)	149	140	100
CO (%)	1.5	0.3	0.15
CO_2 (%)	12.0	5.0	4.0
O_2 (%)	7.0	9.0	11.0

*See reference [11].

Table 7. Summary of CO, CO_2 Concentration and O_2 Depletion Within the Metrorail Car Mock-Up, at the Ceiling and 1.5 Meters from the Floor

Test	Time of Peak Reading (min)	Percent CO		Percent CO_2		Percent O_2	
		Ceiling	1.5 m	Ceiling	1.5 m	Ceiling	1.5 m
1	18.3	2.46	.01	6.62	.30	13.97	20.07
2	9.3	.43	.0	.66	.43	19.19	19.72
3	9.0	.50	.0	--	.15	19.96	20.00
4	9.0	2.35	.0	4.17	.05	17.15	17.78
5	8.5	.37	.1	.77	--	20.09	20.15
6	9.0	.70	.0	1.91	.19	19.17	20.22
7	9.0	.56	.0	1.23	.06	19.44	20.21

Table 8. Summary of HCN Gas Concentrations in Metrorail Car Mock-Up for Tests 1 and 4

Test 1		Test 4	
Sampling Time (min)	HCN in Air (ppm)	Sampling Time (min)	HCN in Air (ppm)
3.25 - 5.25	0	3.0 - 3.5	1
5.25 - 7.25	.020	3.5 - 7.0	10
7.25 - 9.25	.600	7.0 - 10.5	20
15.5 - 17.75	.040		
17.75 - 18.5	.300		

Table 9. Summary of the Blood Cyanide and COHb Results for Tests 5 and 6, and HCN Gas Concentrations for Tests 4 Thru 7

Test Number	Animal Number	COHb (%)	Blood CN (μg/ml)	Exposure Time (min)	Average† HCN Concentration (ppm/min)
4*				7.5	9.87
5	1	4.6		20.3	--††
	3	3.7	0.01**		
6	1	12.2		12	2.42
	2	6.4	0.14		
7*				13	0.89

* Animals not used in these tests

** Background Level

† HCN concentration

†† Not measured

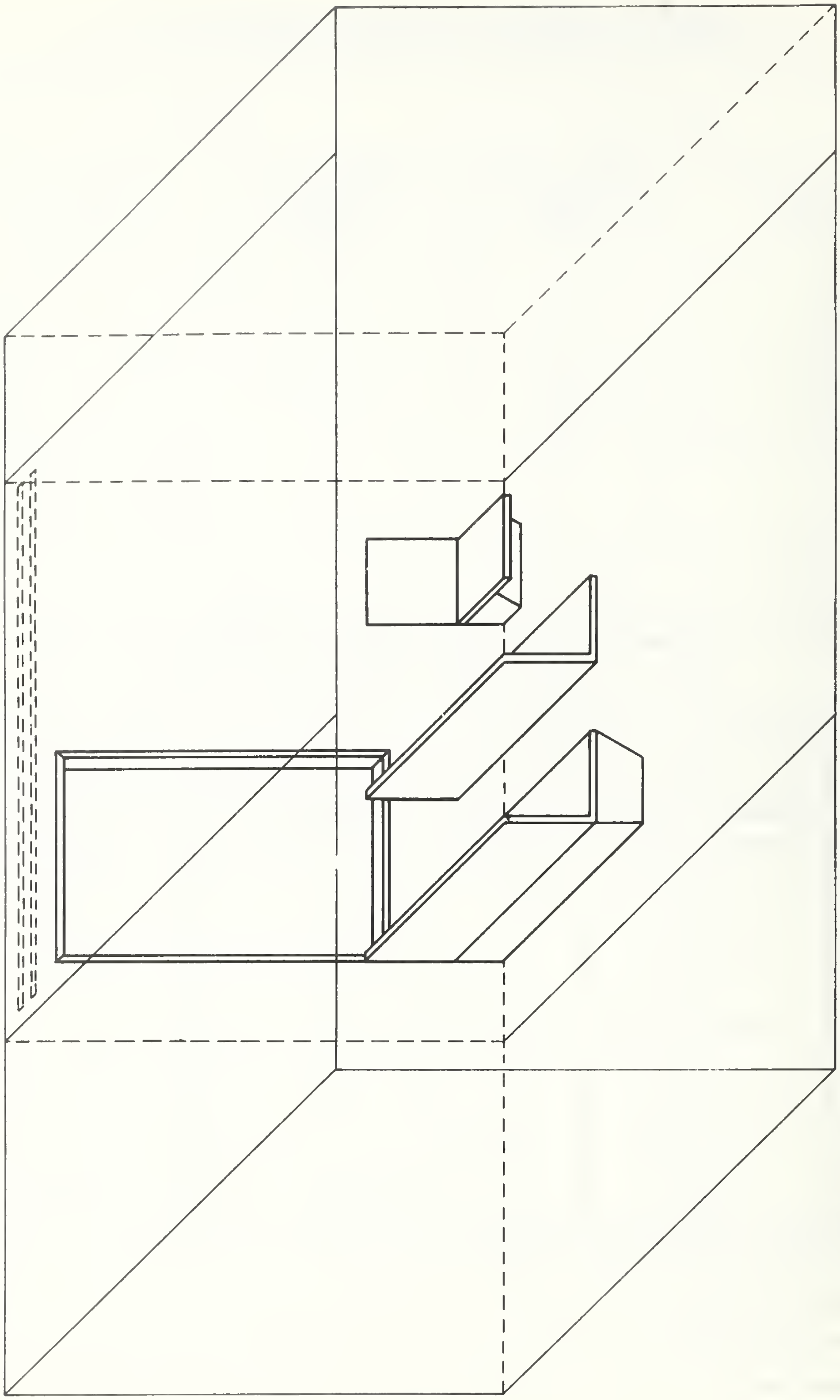

Figure 1. Metrorail Car Mock-Up.

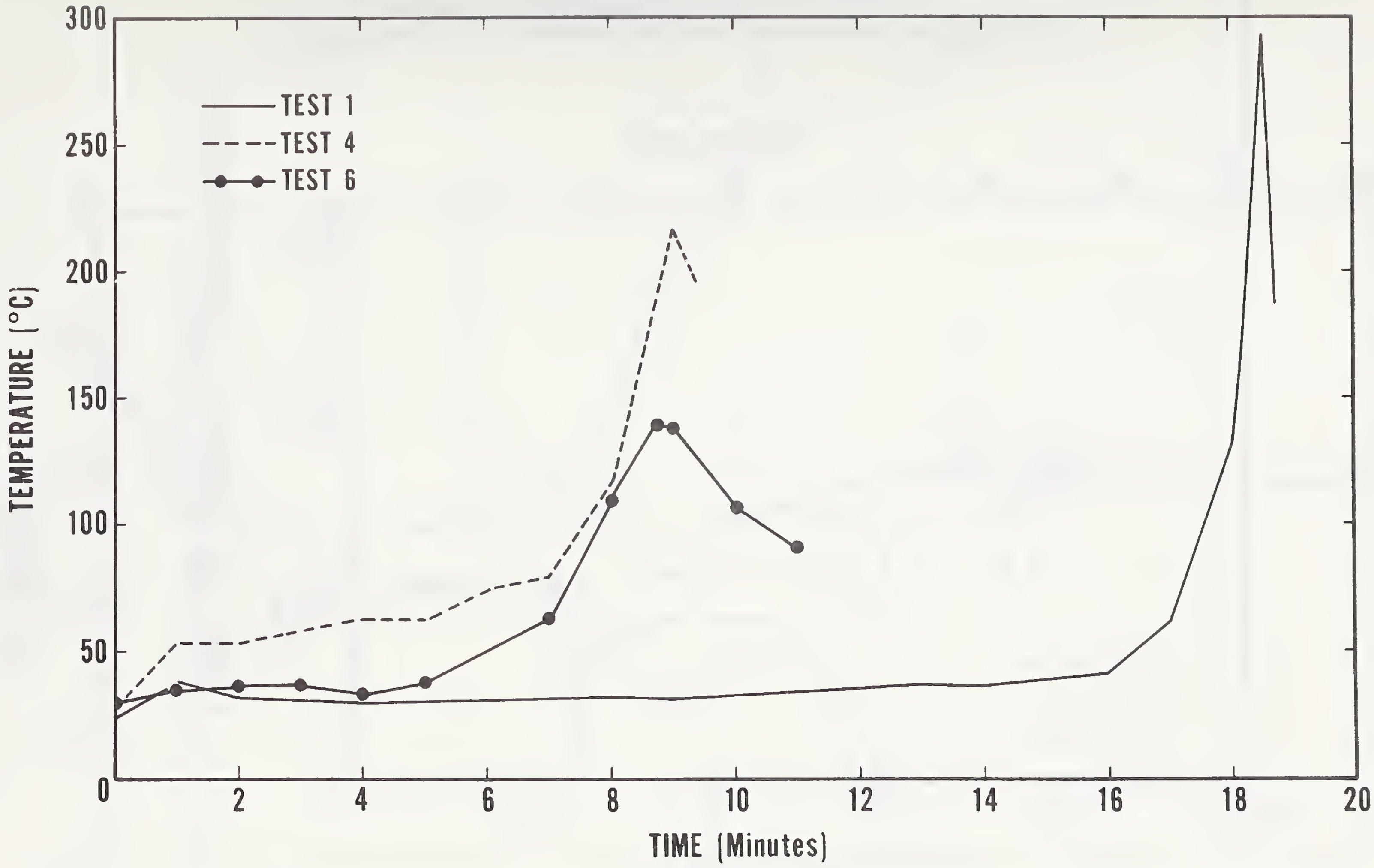

Figure 2. Average Ceiling Temperature in Metrorail Mock-Up - Urethane Foam Seat Cushion.

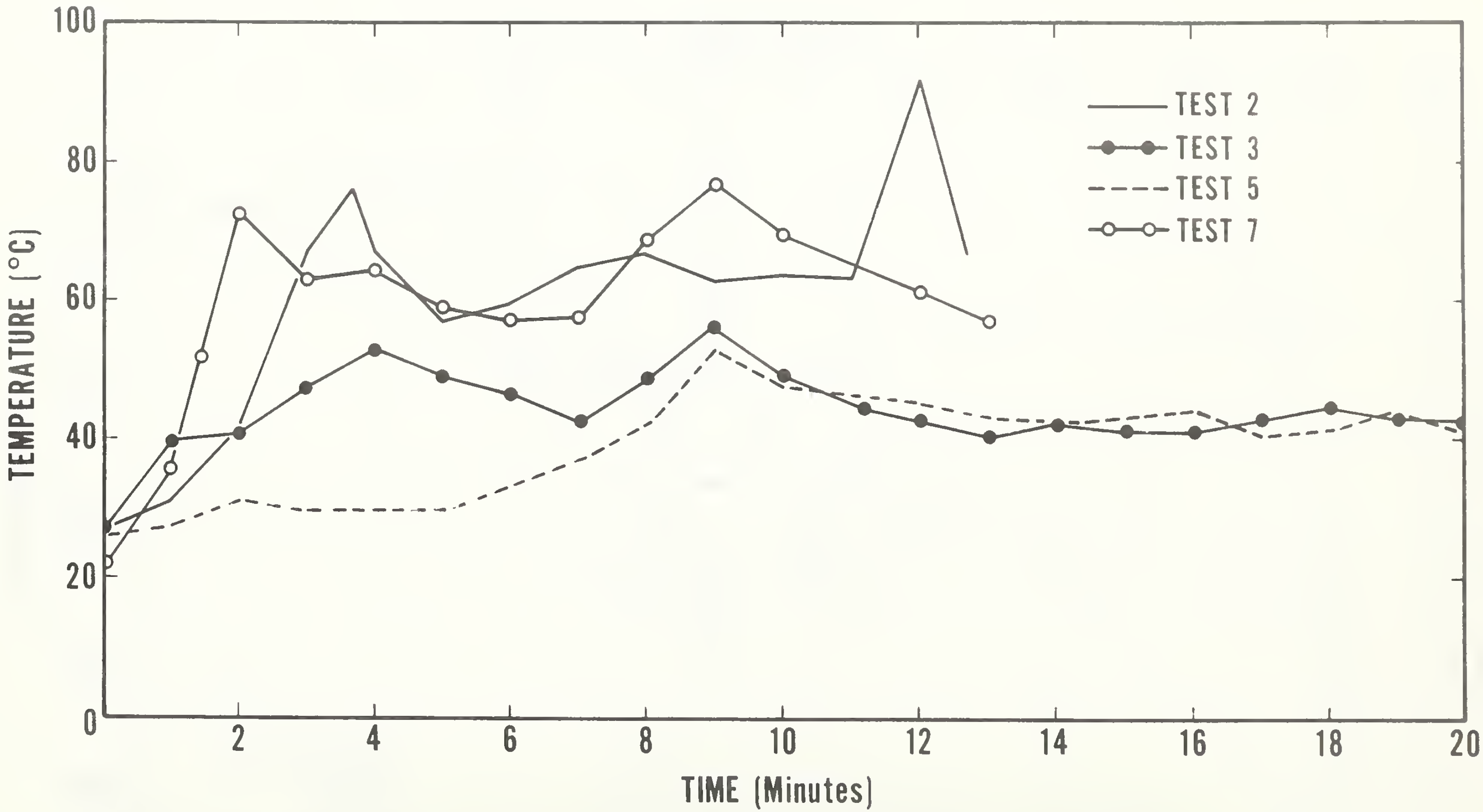

Figure 3. Average Ceiling Temperature in Metrorail Mock-Up (Vinyl/Neoprene Seat Cushions).

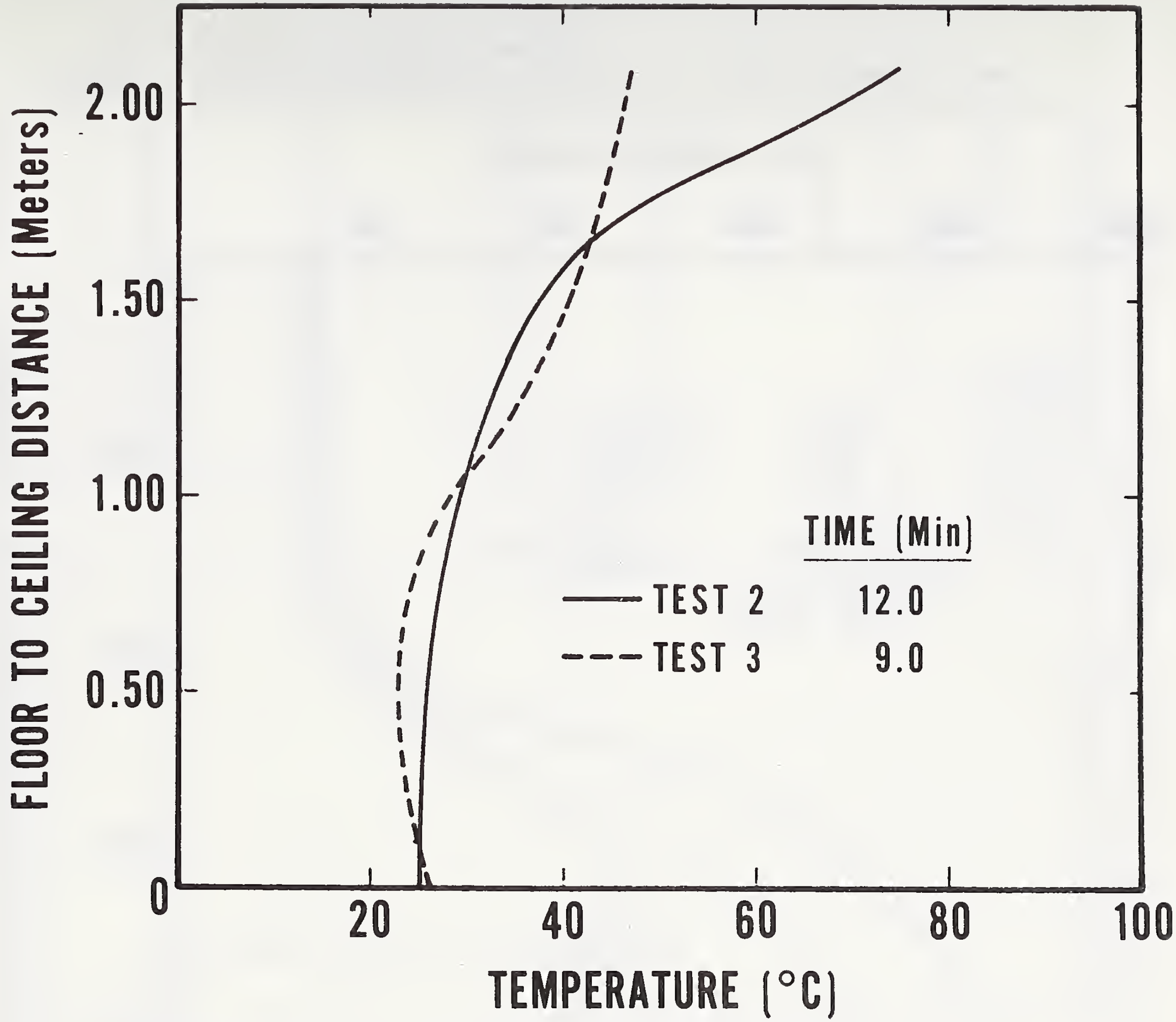

Figure 4. Vertical Temperature Profile 1.4 m from Ignition Point - Aisle (Vinyl/Neoprene Seat Cushion).

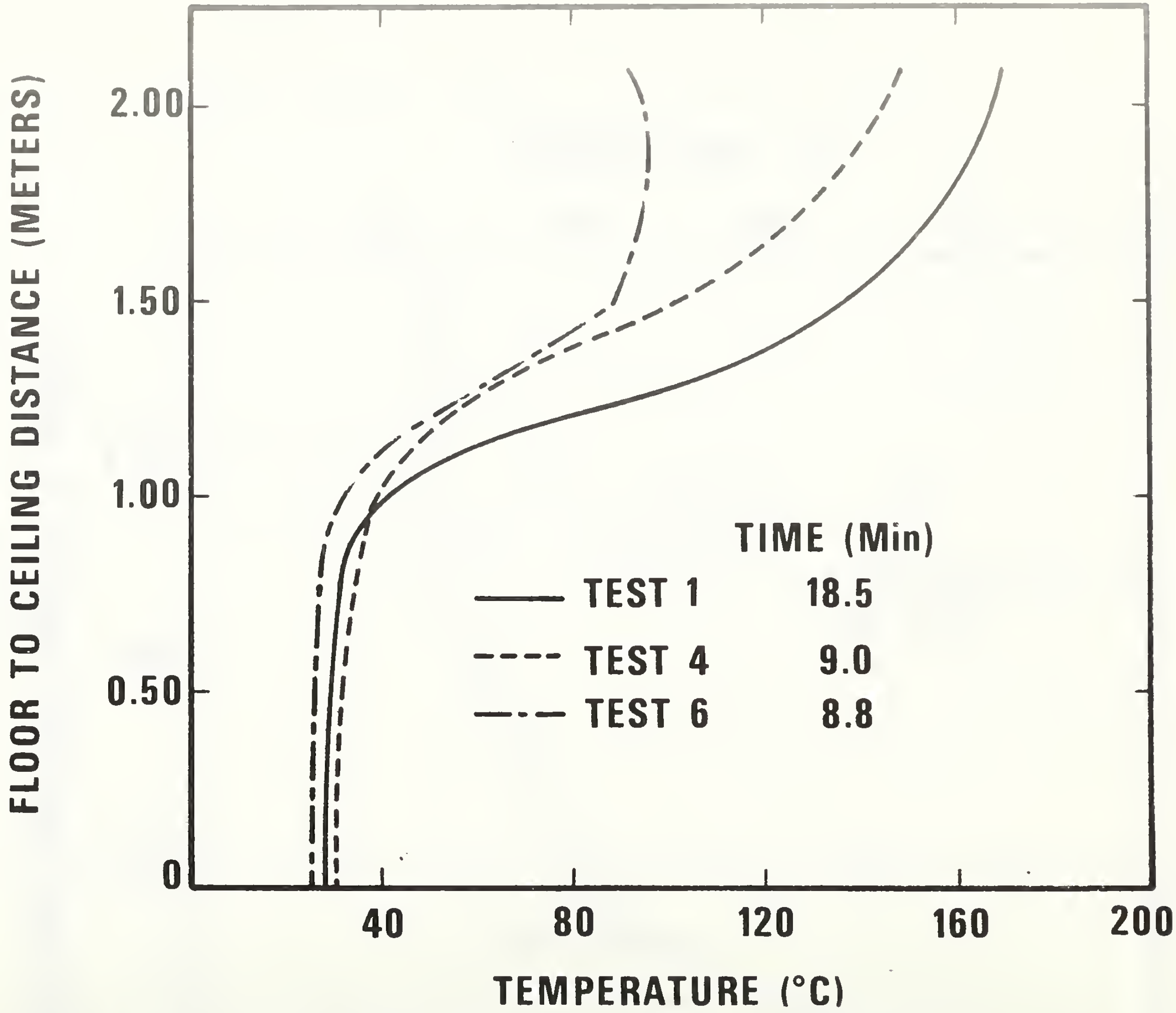

Figure 5. Vertical Temperature Profile 1.4 m from Ignition Point - Aisle (Integral Skin Seat Cushion).

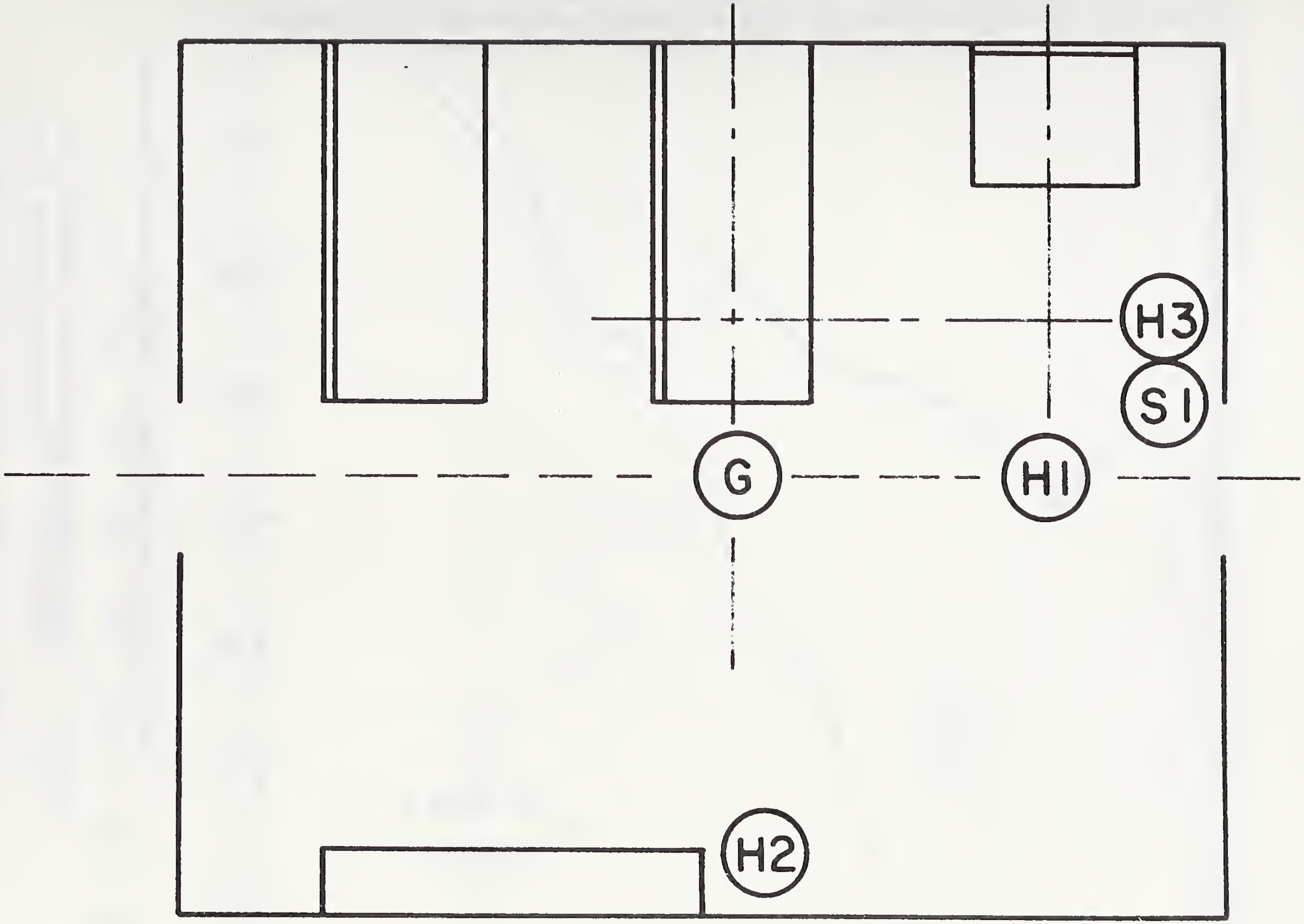

Figure 6. Location of Instruments in Metrorail Fire Tests.

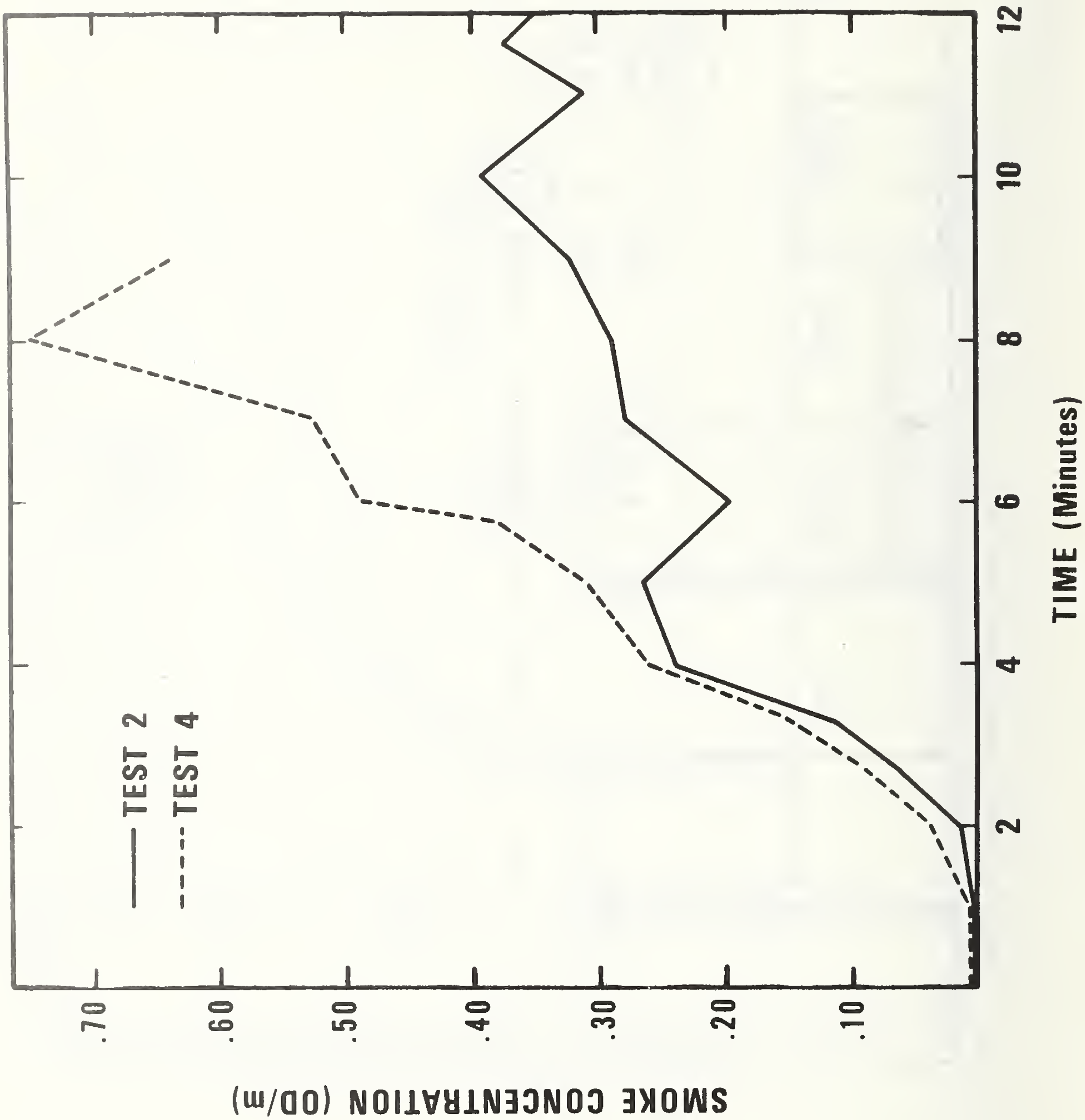

Figure 7. Smoke Density in Metrorail Mock-Up Fire Test 1.5 m from Floor - Along Aisle (Tests 2 and 4).

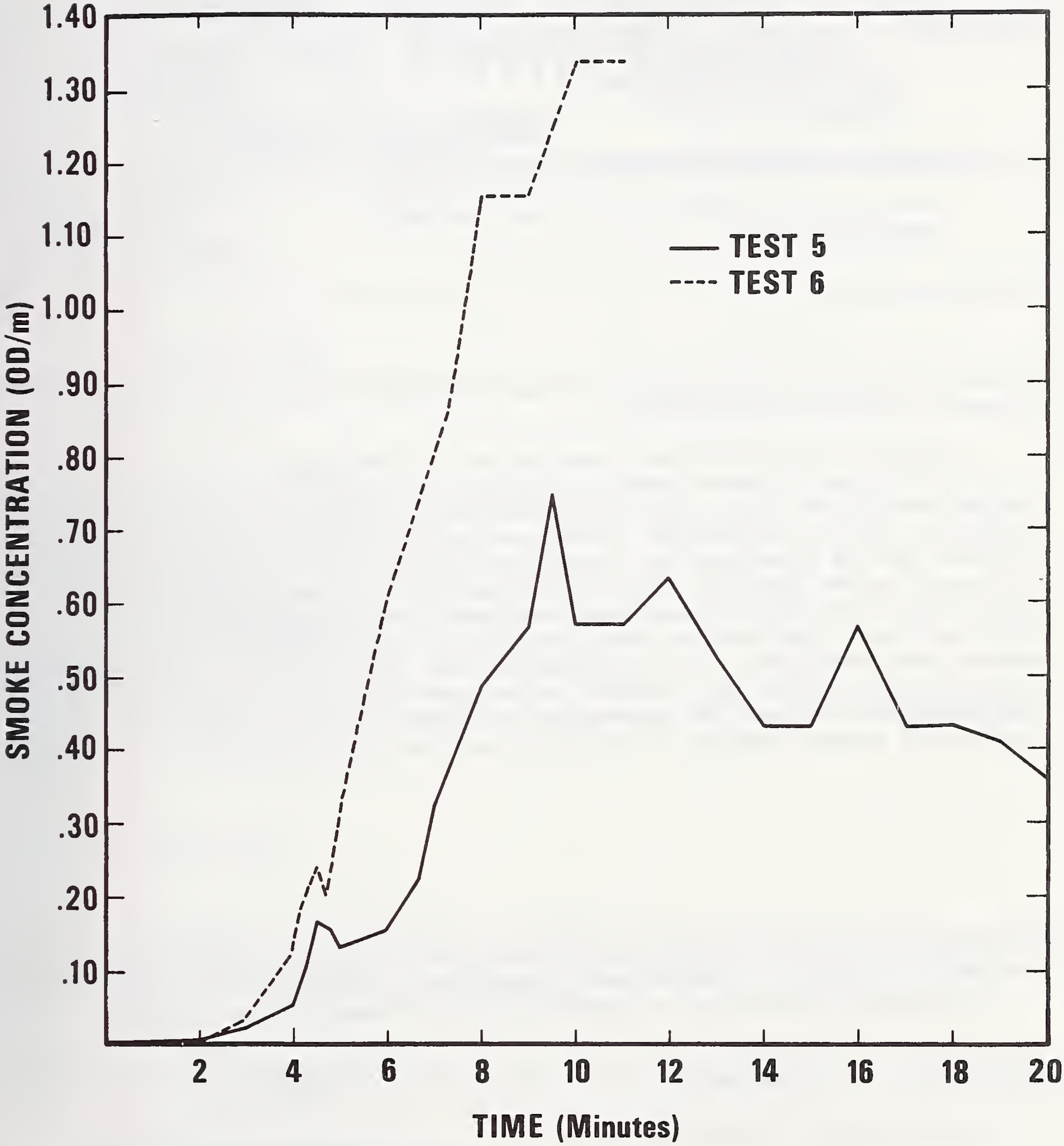

Figure 8. Smoke Density in Metrorail Mock-Up Fire Test 1.5 m from Floor - Along Aisle (Tests 5 and 6).

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 75-971	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE A FIRE HAZARD EVALUATION OF THE INTERIOR OF WMATA METRORAIL CARS	5. Publication Date December 1975 6. Performing Organization Code
7. AUTHOR(S) Emil Braun	8. Performing Organ. Report No.
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234	10. Project/Task/Work Unit No. 492 7371 11. Contract/Grant No.
12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)* Washington Metropolitan Area Transit Authority Washington, D.C.	13. Type of Report & Period Covered Final Report 14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A series of fire tests was conducted for the Washington Metropolitan Area Transit Authority to assist them in assessing the potential for fire hazard in the new Metrorail subway cars. Results of small-scale laboratory tests were found inadequate for this assessment. Results of full-scale tests on mock-ups of the interior (and on a real car for a smoke penetration test) show that the potential for hazard arises primarily from the seat padding and covering and from the plastic wall lining. The hazard arises both from smoke development and from spread of flame and heat. The times to reach unacceptable conditions has been determined for several test conditions. It is recommended that the authorities review these times in the context of what they consider to be appropriate times for safe escape. Recommendations are made for increasing the amount of time available for escape. These would require changes in the seating and wall lining materials.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Flame spread; flammability; full-scale fire tests; laboratory fire tests; Metrorail cars; neoprene; smoke; transportation; urethane.

18. AVAILABILITY	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
[XX] Unlimited [ ] For Official Distribution. Do Not Release to NTIS [ ] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13 [X] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151	UNCLASSIFIED	34
	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price $4.00

USCOMM-DC 29042-P74